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COMPARISON OF SOME MATHMATICAL GROWTH MODELS FOR ESTIMATING OF PYHSIOLOGICAL GROWTH CHARACTERS OF ALFALFA (*MEDICAGO SATIVA* L.)

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Clover plant is a perennial plant and can be harvested 3-6 times depending on growing area. Because of this feature, it is very less used in growth studies. This study was carried out in Yozgat ecological conditions where, 4 harvesting can be taken. Bilensoy (registered variant in Turkey) alfalfa variety growth analysis was made depending on time for each cut. At growth analysis, leaf area index, leaf area ratio, leaf growth ratio, plant growth ratio, relative growth ratio and net assimilation ratios were measured. Growth analysis was made on 5 plants taken from each plot. Measurements were taken at 6 different times of each cut. Richards, Logistic, Weibull, MMF, Gompertz, Exponential, Power, Gaussian, and Rational growth models were used for evaluating. Determination coefficient (R^2) and Mean square error were used as comparison criteria. As a result, Weibull and Richards growth models explained very well plants growth of alfalfa. Leaf area index 96.3; Leaf area ratio 96.1; leaf growth rate 9.4; In the Weibull model with the coefficient of determination, the net assimilation ratio of 95.9 and the plant growth rate of 96.8 have the highest explanation value in the Weibull model.
Keywords: Alfalfa, Mathmatical Growth Models, ecology, growth and development, coefficient of determination.

INTRODUCTION

Turkey makes it possible to produce economically several crops because of favorable ecological conditions. In addition to different production techniques, and different ecological effects cause the production to vary according to the regions. The increase in the observed variability also changes the efficiency of the production. Farmers are to produce high efficiency and quality products to increase their earnings. However, differences in growth and development may limit successful production. Especially, changing ecological conditions can cause great variability in growth and development (Overman and Scholtz, 1999). Producers who cannot adapt to this and cannot fully meet the needs of the plants, cannot be successful. Knowing the physiology of growth and development and making a mathematical description will be useful in guiding producers correctly (Stewart and Dwyer, 1993). Since it is not possible to control the environmental conditions, the growth characteristics of the plants should be well defined to provide the necessary environment for their development.
Growth analysis includes very useful and complex studies that determine the interaction between plant growth and environment (Friend *et al.,* 1962). Understanding of complex relationships is necessary for increasing agriculture production. As is known, plant growth includes vegetative growth between emergence and flowering periods. Any change that may occur in the environment during this period may directly affect the growth and development of the plants (Koç and Barutçular, 2000). It would be beneficial if monitor it closely, as the degree of impact is large or small, it will have an increase or decrease in its productivity (Uzun *et al., 2*001). There is not enough information about growth analyses in alfalfa plant and how the characters that are evaluated in these analyses change depending on time and which mathematical model can be explained better. Increasing the awareness will increase the success rate of the crop. Mustears (1989) stated in his study on underground trifolium that the Richards model was successful in defining the development and changes of plants over time, and the coefficient of indication was at a very high level of 0.99. He stated that the mean square error value decreased accordingly. Brennan and Bolland (2003) determined the change by using Mitserlich model in 15 different locations in their study on underground trifolium. As a result of the study, the coefficient of determination varied between 0.91 and 0.94, while mean square error values varied between 12.67 and 19.03.

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Overman and Scholtz (2003) stated in their study on canine tooth plant that dry matter accumulation showed serious changes in fertilized and non-fertilized conditions and there was a higher amount of dry matter accumulation in the fertilized parcels. They used the Logistics model in their study for modeling, and the coefficient of determination was 98.9% in both applications. Although many plant growths models and characteristics have been explained, but insufficient studies have been done in clover. Modeling for changes in physiological characters is considered important. In this study, it was tried to explain the average growth of some physiological characteristics of the four cuttings of alfalfa tested under Yozgat conditions by mathematical growth models.

MATERIALS AND METHODS

The study was carried out with a contracted producer in Yozgat ecological conditions. The Bilensoy variety, which is grown on large area throughout Yozgat, was used as the material in the study. This variety can be grown successfully in the climatic conditions of Central Anatolia and can give 4 cuttings per year. Yozgat is in Turkey's central part and has a continental climate (Fig. 1). It is 1400 meters above sea level. Clover cultivation has not been done before in the land where the experiment was conducted. It was cultivated as a front crop maize. For this reason, it has prevented all plants from being affected differently.

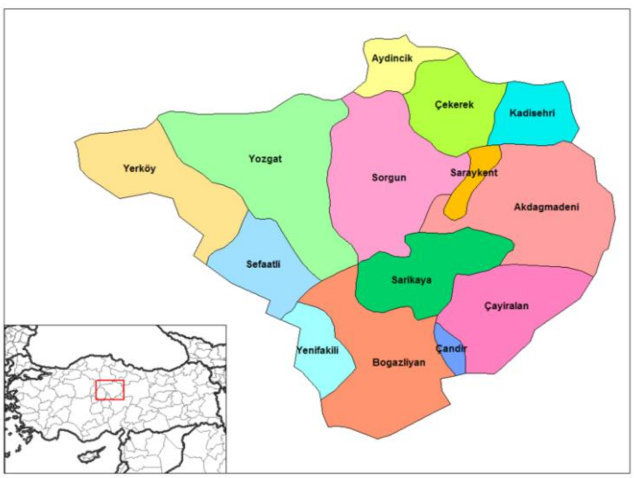

Figure 1. Yozgat province location in Turkey.

The soil of the area where the trials were conducted is slightly calcareous. The pH was determined as 7.9, organic matter 1.23%, phosphorus 3.8 kg/ha, nitrogen 1.7 kg/ha and potassium 15.1 kg/ha. Alfalfa plants can be cut four times and therefore, data were taken four times. Measurements were made 6 times for each cut and the data obtained were evaluated. While determining the plants in the plots, 1 x 1 m^2 of mat was thrown and five plants were randomly selected under this mat. Measurements were made on selected plants. To ensure randomness in the trials areas, each plant was labeled and measured by drawing lots.

The samples taken from the field were transported carefully and quickly to the laboratory where, leaf area index, leaf area ratio, leaf growth rate, plant growth rate, relative growth rate and net assimilation rate used in growth analysis were determined. The mathematical models used in the study are given in Table 1. Models are nonlinear because the plants show a non-linear growth within the period of growth and development.

Table 1. Mathematical growth models used to determine the growth of physiological characters.

Models	Equations
Richards Model	$Y = \dfrac{a}{(1+e^{b-cx})^{1/d}}$
Logistic Model	$Y = \dfrac{a}{1+be^{-cx}}$
Weibull Model	$Y = a - be^{-cx^d}$
MMF Model	$Y = \dfrac{ab+cx^d}{b+x^d}$
Gompertz Model	$Y = ae^{-e^{b-cx}}$
Exponential Model	$Y = ae^{bx}$
Power Model	$Y = ab^x$
Gaussian Model	$Y = ae^{\frac{-(x-b)^2}{2c^2}}$
Rational Function Model	$Y = \dfrac{a+bx}{1+cx+dx^2}$

Coefficient of determination (R^2) and mean square error (MSE) values were used for comparing the models. The model with a high coefficient of determination and a low mean square error was accepted as successful.

RESULTS AND DISCUSSION

The results indicated that the determination coefficients were generally high (Table 2). This may be due to the dynamic nature of the models (Mathieu *et al.*, 2009). While determination coefficients and mean square error values obtained in Weibull model were with the highest 96.3 and 0.011 error value for the leaf area index. The lowest determination coefficient value was obtained in the Gaussian model 80.3. However, the highest mean square error value was obtained with the Gompertz model with 0.445.

In terms of leaf area ratio, the highest R^2 value was obtained as 96.1 and the MSE value was 0.015 in the Weibull model, while the lowest value was in the Gaussian model with 80.6. The highest mean square error value of 1.156 was obtained from the Exponential model.

The highest determination rate of leaf growth rate was in Weibull model with a value of 94.4. The lowest determination was obtained from the Exponential model with a value of

Table 2. Explanation of some physiological characters of alfalfa plants.

Models	Equality	Comparison Criteria	Physiological Characters				
			LAI	LAR	LGR	NAR	PGR
Richards Model	$Y = \frac{a}{(1+e^{b-cx})^{1/d}}$	R^2	90,1	92,3	90,1	96,4	94,8
		HKO	0.019	0.305	0.051	0.013	0.043
Logistic Model	$Y = \frac{a}{1+be^{-cx}}$	R^2	91.3	92.1	90.3	91.6	91.8
		HKO	0.033	0.349	0.612	0.121	0.132
Weibull Model	$Y = a - be^{-cx^d}$	R^2	96.3	96.1	94.4	95.9	96.8
		HKO	0.011	0.015	0.033	0.024	0.014
MMF Model	$Y = \frac{ab+cx^d}{b+x^d}$	R^2	88.4	89.0	86.7	88.9	88.8
		HKO	0.076	0.061	0.179	0.073	0.78
Gompertz Model	$Y = ae^{-e^{b-cx}}$	R^2	88.1	88.4	82.7	86.6	85.8
		HKO	0.445	0.412	0.517	0.493	0.611
Exponential Model	$Y = ae^{bx}$	R^2	82.2	81.9	77.5	79.0	80.2
		HKO	0.115	1.144	0.342	0.251	0.212
Power Model	$Y = ab^x$	R^2	88.3	81.1	77.8	73.6	78.2
		HKO	0.241	0.977	1.368	1.672	1.221
Gaussian Model	$Y = ae^{\frac{-(x-b)^2}{2c^2}}$	R^2	80.3	80.6	78.8	79.4	79.2
		HKO	0.168	1.156	0.348	0.251	0.248
Rational Function Model	$Y = \frac{a+bx}{1+cx+dx^2}$	R^2	89.4	90.6	87.6	89.3	88,7
		HKO	0.224	0.193	0.364	0.252	0.148

77.5. In terms of mean square error, the highest value was observed in the Power model with 1.368, while the lowest value was in the Weibull model with 0.033.

The amount of determination of the net assimilation rate was between 73.6 and 96.4. While the highest determination was in the Richards model, the lowest was in the Power model. In case of mean square error, the lowest value was in the Richards model with 0.013, while the highest error value was in the Power model with 1.672.

In the plant growth rate, the determination rate was 96.8 in Weibull model. The lowest value was in the Power model with 78.2. In terms of mean square error, the lowest value was in the Weibull model with 0.014, while the highest value was again in the Power model with 1.221.

The basis of growth in plants is through substance exchange. On the other hand, matter exchange is the basis of growth (Kyle *et al.*, 1983). The chain of events that causes substantial changes include events such as photosynthesis and respiration. Photosynthesis and respiration are very complex events, and they produce the substances necessary for the plant to grow and develop (Buck-Sorlin *et al.*, 2005). Since growth is a quantitative event, it is measurable. Increase in plant height, dry weight, leaf area or any change in the leaves of the plant are indicators of growth and development (Garbey *et al.*, 2006). Development essentially refers to the differentiation of plants (Dingkuhn *et al.*, 2006). Development is a qualitative phenomenon and can only be investigated by observation. Changes such as emergence, different leaf and stem formations, flowering, fruit formation etc. are included in development. However, these events are mostly not as independent from each other, but in a complex system which are entangled and has mutual effects (Jourdan *et al.*, 1997).

Numerous cells in the plants, capable of reproducing rapidly, come together in a certain organic order and form different organs. When it comes to the growth of organs, it is the growth resulting from the average growth of the cells that make up these organs (Louarn *et al*, 2008). For this reason, the growth of organs is ensured both by the increase in the number of cells of the organs because of the division of the meristematic divisible cells in that organ, and by the increase in volume of all permanent tissue cells participating in the structure of the organ (Prusinkiewicz and Rolland-Lagan, 2006). In an organ, there can be both divisible and invariant tissue cells, as well as cells that have reached different growth stages (Rowe and Speck, 2005). This causes the formation of different growth zones in an organ. As a result of these, the differences observed in plants should be put forward clearly. To do this, it should be recognized both physiologically and mathematically. Since the alfalfa crop used in our study is harvested more than one times a year, it has more than one growth period. A fast physiological structure makes it difficult to define mathematically. However, this study helped to explain the physiological characteristics of the alfalfa plant mathematically.

Growth is expressed as the net increase in dry matter of a plant per unit of leaf area per unit time. It is an important factor in the growth and development of the leaf area that the leaf surface retains CO_2 to keep the light from the sun and use it in photosynthesis (Charles-Edwars *et al.*, 1981). This is the determinant of the physiological events taking place within the plant. In growth analysis, two basic factors should be well known, i.e., the production of dry weight and leaf area. In this

study leaf-related studies were carried out because the growth is directly related to the leaf growth in the plants. It has been determined by many researchers that as the plant grows in height, the leaf ratio decreases, the dry matter and crude protein yield increases, and the crude protein ratio decreases partially due to the decrease in the leaf ratio (Manga, 1981; Akbari and Avcıoğlu, 1994; Aydın *et al.*, 1994; Tahtacıoğlu *et al.*, 1994; Şengül and Tahtacıoğlu, 1996). It is possible to determine these and similar changes with growth analysis.

***Conclusion*:** The results indicated that the Weibull model has generally achieved a certain level of growth and development in terms of all features. This model was followed by the Richards model. The high success rate of both models indicates that these can be used successfully in defining the growth and development of alfalfa plants. It was determined that the Power and Gaussian models could not adequately identify the clover plants. It will be beneficial not to choose these models in future studies. It is very difficult to find studies on the growth of forage crops, and especially studies to explain the changes in physiological characters. The growth of perennial plants such as alfalfa requires quite difficult and time-consuming studies. It is believed that this study will be beneficial for researchers who are interested in growth and development studies in crops.

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